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Denver

Plasma-based **particle acceleration** & energy coupling in **Magnetized Plasmas**

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NSF (applied)

2019 ATF Users Meeting: New Proposal

Scientific Case

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Katsouleas, T., Dawson, J. M., Phys. Rev. Lett. **51**, 392 **(1983)**

utilize gyro-kinetics

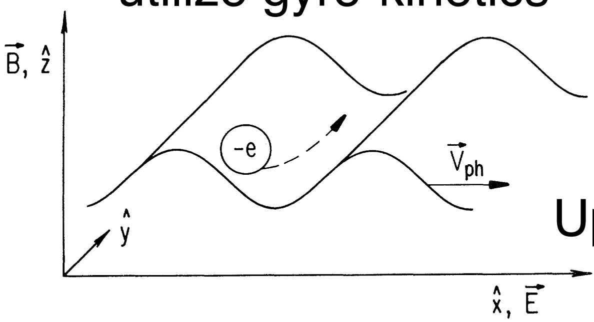

FIG. 1. An electron trapped by a potential trough moving at $\vec{V}_{ph}$ sees an electric field from the Lorentz transformation $\gamma_{ph}\vec{V}_{ph}\times\vec{B}/c$ which accelerates it across the wave front.

Linear regime

Transverse B-field
Upper-Hybrid Wave Mode

NO dephasing

TABLE I. Sample parameters to reach 1 TeV.

n (cm^{-3})	λ (μm)	ϵ	B_{kG}	Δy (m)	Δx (m)	Δx_{BWA} (m)	P_i (W/cm^2)
10^{17}	10	0.9	90	3	35	3500	10^{15}
10^{18}	1	0.5	50	0.6	20	850	10^{16}
10^{20}	0.3	0.2	600	0.5	5	1000	5×10^{16}

Δy >> plasma dimension !

Axial B-field – L and R modes

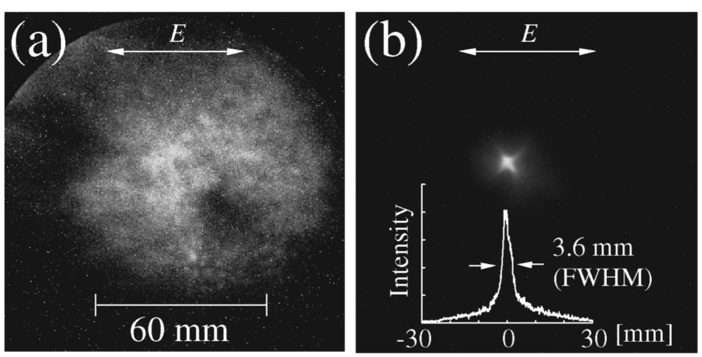

FIG. 2. Typical images of electron deposition on the DRZ screen. $N_{He}=4\times10^{19}$ cm^{-3} and of 12 TW laser pulse. (a) $B=$ 0 T and (b) $B=0.20$ T.

better emittance
more charge

but attributed to
change in pre-plasma

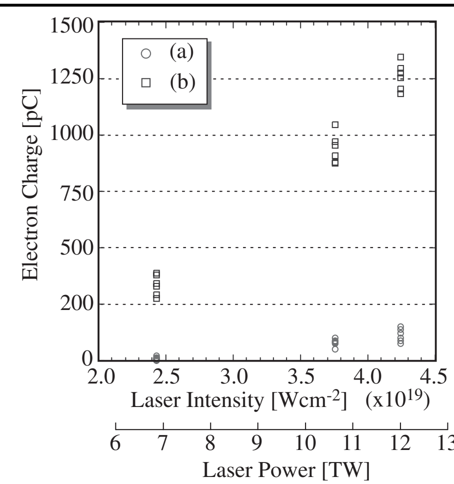

FIG. 4. The intensity dependence of the total charge of the accelerated electrons for $N_{He}=4\times10^{19}$ cm^{-3}. (a) $B=0$ T and (b) $B=0.20$ T. The laser power is also indicated in the horizontal axis.

Hosokai, T., et al, Phys. Rev. Lett. **97**, 075004 **(2006)**

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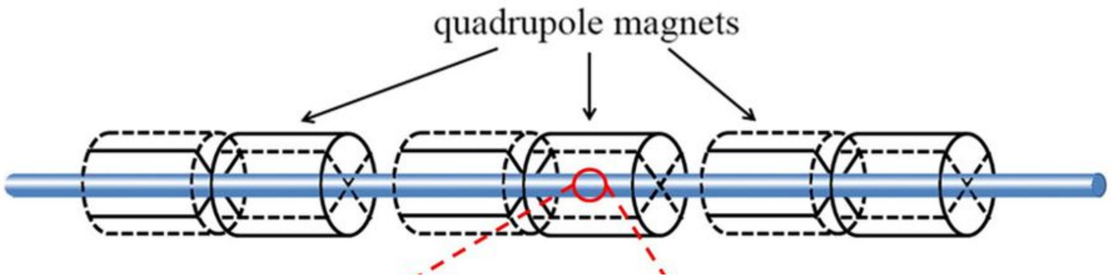
L. Yi., et al, Scientific Reports 4, 4171 **(2014)**



Quad magnets – static field applied

Wakefield driver – quality preserved

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other past works –
1. analyzed the effect of significant gyro-frequency to plasma frequency ratio
2. shown that excessive axial field can lead to disruption of the plasma bubble
3. etc.

Can applied B field - **better driver guiding & improve accelerated beam quality**

continuous focusing needed - magnetized RF cavity

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **8**, 072001 (2005)

Effects of high solenoidal magnetic fields on rf accelerating cavities

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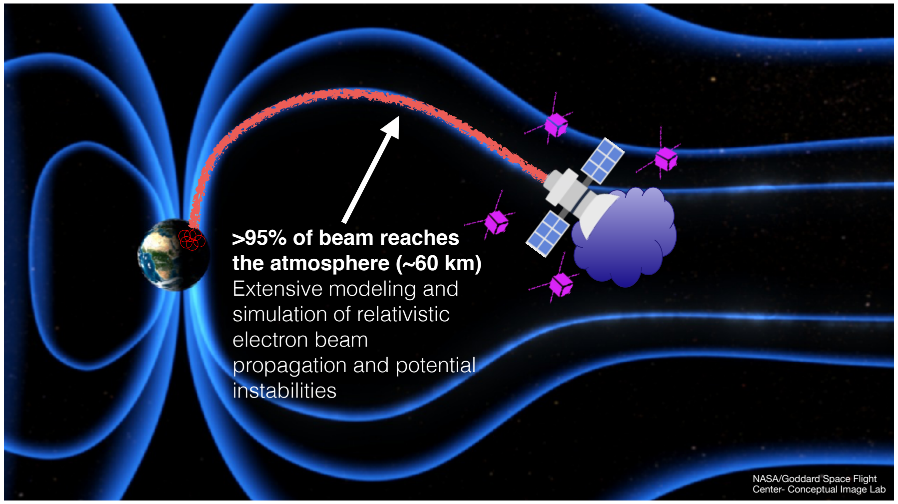
relevant radiation-belt physics studies using relativistic electron beam on-board a space-craft



Lab-based modeling – wave-particle interaction and energy coupling

Linear plasma wave

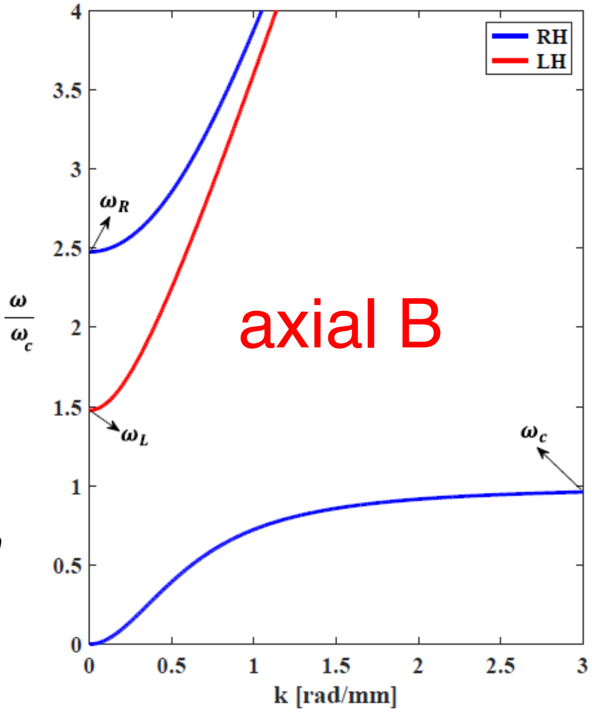
Plasma dispersion relations

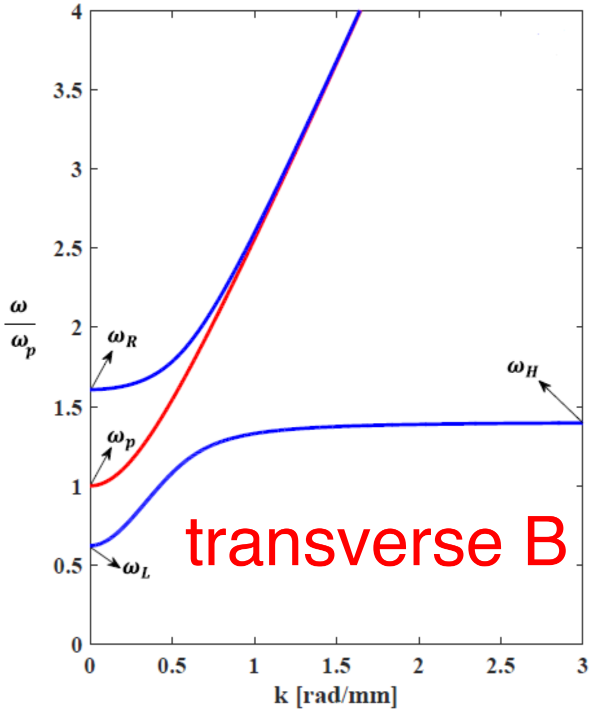
$$\omega_c \simeq \Omega_c \simeq \frac{eB}{m_e}$$

$$\omega_{pe} = \sqrt{\frac{n_0 e^2}{\epsilon_0 m_e}}$$

$$\text{Transverse EM mode} : \omega$$

$$\omega = k v_b \pm n \frac{\omega_c}{\gamma}$$





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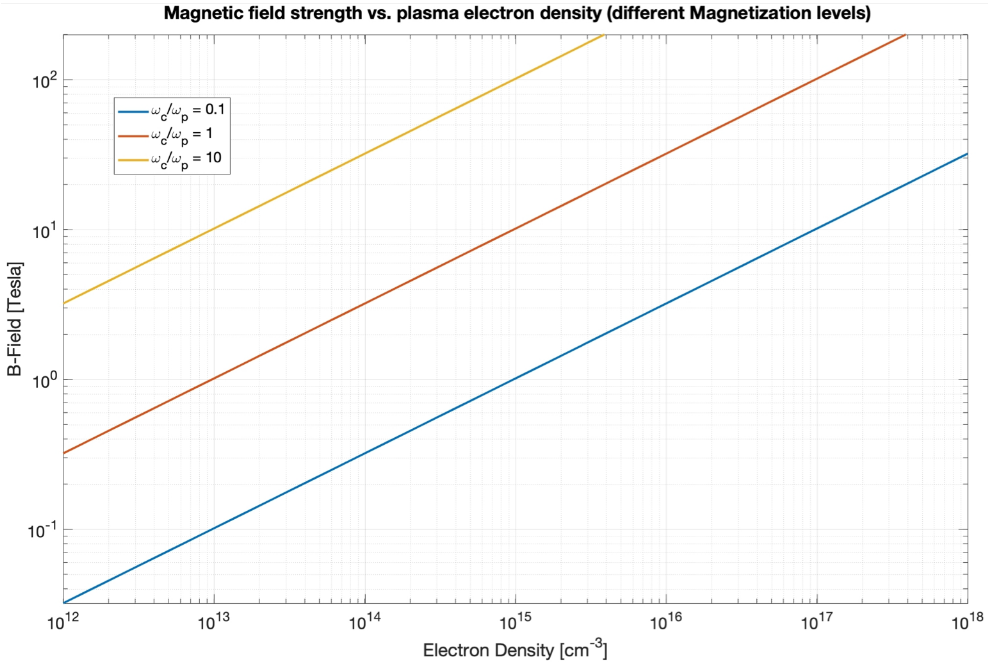


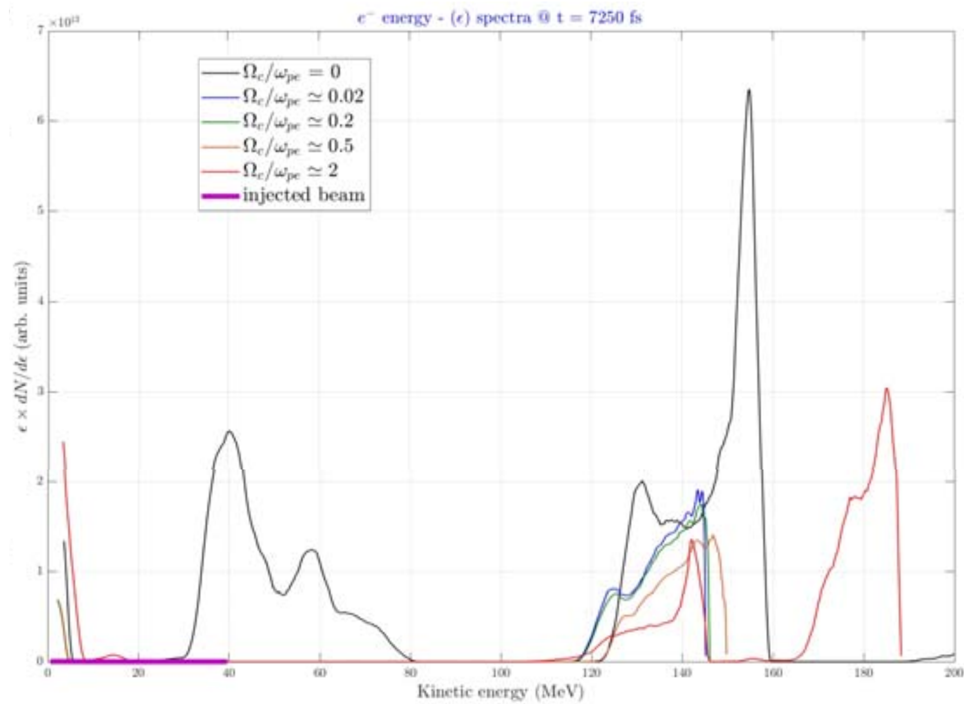
10 µm CO_2 laser – naturally **1/100 plasma density**

Co-located with a tunable and ultrashort electron beam

Suitable for laser-ionized or laser-driven magnetized plasma acceleration studies

2.5D PIC simulations – effect of magnetization level on beam energy spectra

Optimal magnetization levels – for accessing different magnetized plasma waves



Experimental Setup

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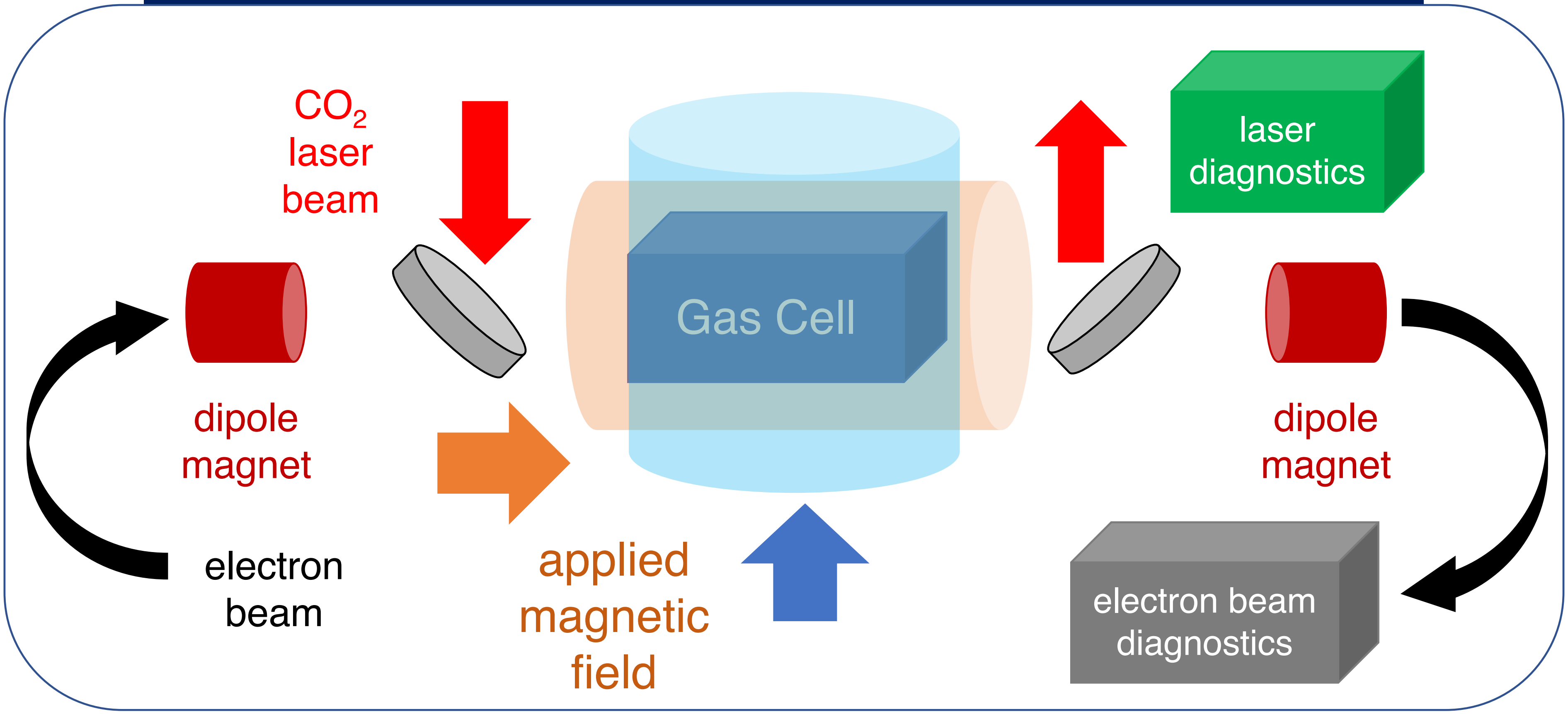
ultra-relativistic magnetized plasma wave excitation



Plans

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Year 1

Laser-ionized plasma – beam-plasma interactions

- Pressure scan with fixed applied B-field
- Axial and transverse B-field configuration
- Preliminary studies with rare-earth or other permanent magnet
- Observe beam energy spectrum
- Beam profile (transverse)

Year 2

Laser-ionized plasma – beam-plasma interactions

- scan over beam energies
- Scan over beam properties (spot-size, charge length)
- scan over magnetic field orientations

Plans contd…

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Year 2 continued

- Preliminary laser-driven waves in magnetized plasmas (effect on laser exit mode and laser energy)

Year 3

Laser and beam-plasma – magnetized plasmas

- Try stronger magnetic fields (superconducting ? others…)
- Laser-driven plasma interactions with magnetic field orientations
- Nonlinear laser-driven plasma wave and ultrashort beam overlap
- Optimize pathways for beam energy gain and emittance enhancement

Electron Beam Requirements

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Parameter	Nominal	Requested
Beam Energy (MeV)	50-65	*10 – 50 MeV*
Bunch Charge (nC)	0.1-2.0	*Bunch length & emittance vary with charge*
Compression	Down to 100 fs (up to 1 kA peak current)	*0.1 to 10 ps*
Transverse size at IP (sigma, um)	30 – 100 (dependent on IP position)	*It is possible to achieve transverse sizes below 10 um with special permanent magnet optics.*
Normalized Emittance (um)	1 (at 0.3 nC)	*Variable with bunch charge*
Rep. Rate (Hz)	1.5	*3 Hz also available if needed*
Trains mode	Single bunch	*Multi-bunch mode available. Trains of 24 or 48 ns spaced bunches.*

Special Equipment:

magnetic field – permanent or other electromagnet setup

transverse deflecting cavity, bolometer

CO_2 Laser Requirements

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Year 1 (regen only, 1.5 or 3 Hz)
3 GW max (2 ps, 6 mJ)
~ 10.2 um
M^2 ~1.5
linear polarization (circular available at slightly reduced power)
likely to be sufficient for laser ionization

Year 2 (full power, ~1 shot per minute)
isotopic gas in final amplifier
2 TW max (2 ps, 4 J, single pulse)
10.2 um
M^2 ~ 2
linear polarization
Required for

2019 Experiment Time Estimates

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Run Hours (include setup time in hours estimate):
Number of electron beam only hours: 0
Number of CO_2 laser hours
delivered to laser experiment hall ("FEL room"): 0
Number of CO_2 laser hours, + ebeam,
delivered to electron beam experiment hall: **60 - 80 hours**

Overall % setup time: **25-35%**

Hazards & installation requirements:
Large installation (chamber, insertion device etc…): Y/N
Laser use (other than CO_2): No
Cryogens: Possibly needed in Year 3
Introducing new magnetic elements: **Yes Critical**
Introducing new materials into the beam path: No
Any other foreseeable beam line modifications: No